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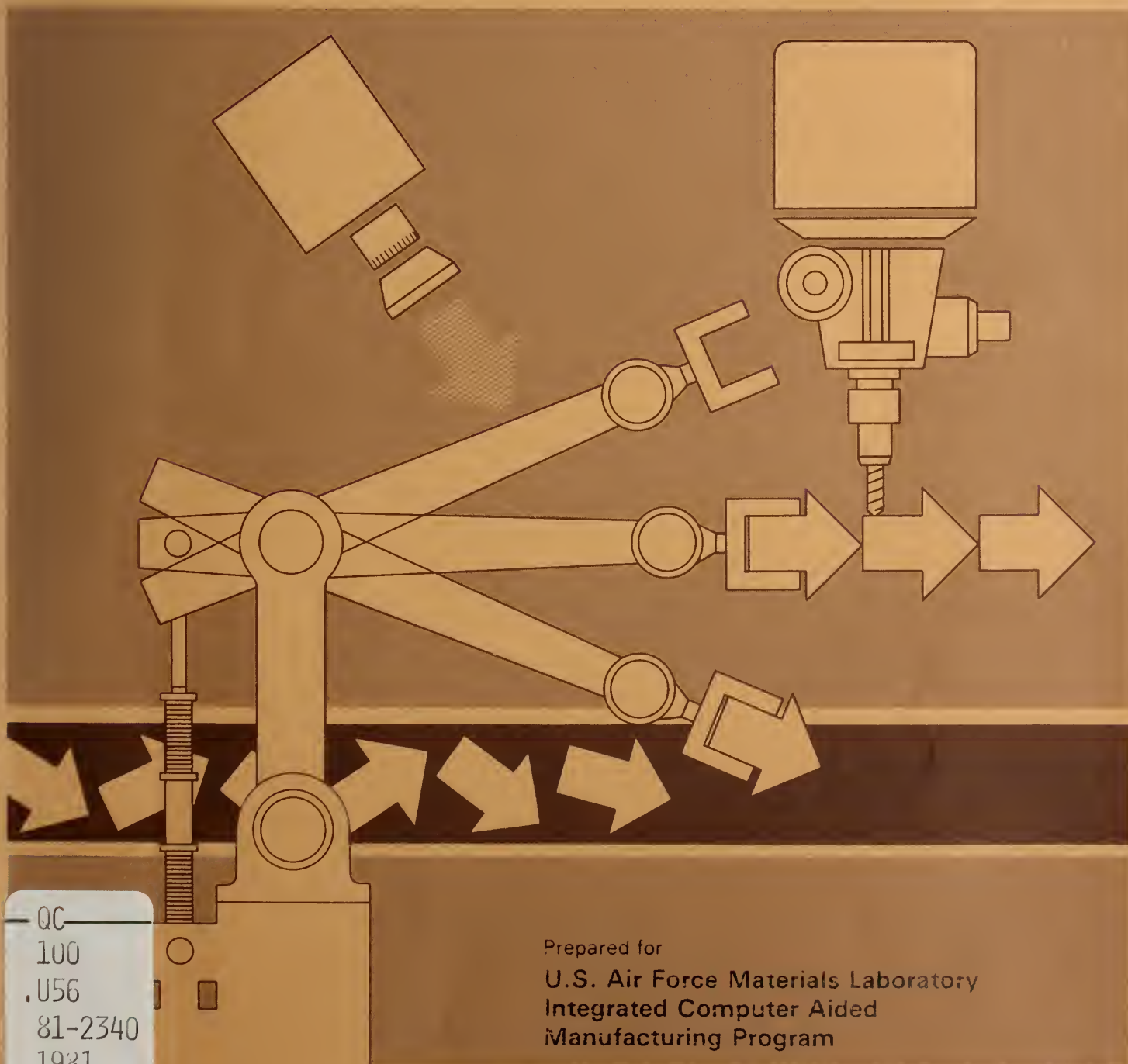


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A Glossary of Terms for Robotics

October 1981



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Prepared for
U.S. Air Force Materials Laboratory
Integrated Computer Aided
Manufacturing Program

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A GLOSSARY OF TERMS FOR ROBOTICS

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Integrated Computer Aided
Manufacturing Program



U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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INTRODUCTION

This glossary has been assembled in order that users, vendors, researchers, students, teachers, and others involved with the rapidly developing field of robotics may communicate in terms which are shared and understood in common. The document does in fact represent only an initial draft of definitions collated or developed by the authors.

Preparation of this document was accomplished by the Automation Technology Program at the National Bureau of Standards as one phase of a project funded by the Air Force Systems Command Integrated Computer Aided Manufacturing Program under Military Interdepartmental Purchase Request SY1457-78-00003. Contract assistance for the project was most ably provided by Dr. Thomas B. Sheridan of Sheridan and Associates, West Newton, Mass. It is the belief of this project team that the use of emerging robotics technology along with that of numerical control of machining processes offers great promise for improving productivity in discrete part batch manufacturing operations.

The criterion for inclusion of terms is simply that the authors and sponsors sought those which are most troublesome, most used, and most important within the general field of industrial robotics, without the document becoming unbearably long. For the most part, basic terms of English usage are excluded, as are computer science, common mathematical terms and mechanical or electrical engineering terms which may readily be found in conventional English dictionaries or dictionaries of mathematics or technology.

To serve a tutorial function as well as a reference function, terms in the glossary are grouped into similar categories. Fourteen categories are defined with some being further segmented for clarity. A full alphabetized listing of terms is provided in the Appendix, with page references to the definitions. Cross references to other terms which are more general, or which provide comparison or contrast, are also given. In a few cases graphical illustrations are presented.

ACKNOWLEDGEMENT

The assistance of the following institutions and individuals is gratefully acknowledged:

The United States Air Force ICAM Program for providing basic support to NBS as well as review of the glossary.

Computer Aided Manufacturing International, Inc. (CAM-I) which published a glossary of Computer Aided Manufacturing terms, R-78-SC-01, some definitions of which are used with permission in the present glossary, and some terms from which are redefined to fit the robotics context.

The Japan Industrial Robot Association (JIRA) which for several years has had an active project to standardize robotics terms. Particularly appreciated were discussions with Professor Y. Hasegawa of Waseda University in Tokyo who has been an active participant in JIRA activities.

Last but not least, the following individuals are thanked for their many and varied contributions: Professor Rainan Banerji of Temple University; Mr. Christopher Barnett of MIT, Dr. Antal Bejezy of Jet Propulsion Laboratory, California Institute of Technology; Professor Nathan Cook of MIT, Mr. Joseph Engelberger of Unimation Co; Mr. Richard Hohn of Cincinnati Milacron Co; Mr. Frans Van Dyck of MIT; Dr. Daniel Whitney of C.S. Draper Laboratory.

Thomas B. Sheridan

Bradford M. Smith

1. TYPES OF MANIPULATORS

ROBOT

A mechanical device which can be programmed to perform some task of manipulation or locomotion under automatic control.

MANIPULATOR

A mechanism, usually consisting of a series of segments, jointed or sliding relative to one another, for the purpose of grasping and moving objects usually in several degrees of freedom. It may be remotely controlled by a computer or by a human.

INDUSTRIAL ROBOT

A programmable, multi-function manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks.

SPACE ROBOT

A robot used for manipulation or inspection in an earth orbit or deep space environment.

INTELLIGENT ROBOT

A robot which can be programmed to make performance choices contingent on sensory inputs.

PICK AND PLACE ROBOT

A simple robot, often with only two or three degrees of freedom, which transfers items from place to place by means of point to point moves. Little or no trajectory control is available. Often referred to as a "bang-bang" robot.

FIXED STOP ROBOT

A robot with stop point control but no trajectory control. That is, each of its axes has a fixed limit at each end of its stroke and cannot stop except at one or the other of these limits. Such a robot with N degrees of freedom can therefore stop at no more than 2 locations (where location includes position and orientation). Some controllers do offer the capability of program selection of one of several mechanical stops to be used. Often very good repeatability can be obtained with a fixed stop robot.

BANG-BANG ROBOT

See Pick and Place Robot

ANDROID

A robot which resembles a human in physical appearance.

PROSTHETIC DEVICE

A device which substitutes for lost manipulative or mobility functions of the human limbs.

LIMITED-DEGREE-OF-FREEDOM ROBOT

A robot able to position and orient its end effector in fewer than six degrees of freedom.

RECORD-PLAYBACK ROBOT

A manipulator for which the critical points along desired trajectories are stored in sequence by recording the actual values of the joint position encoders of the robot as it is moved under operator control. To perform the task, these points are played back to the robot servo system.

MOBILE ROBOT

A robot mounted on a movable platform.

SENSORY-CONTROLLED ROBOT

A robot whose program sequence can be modified as a function of information sensed from its environment. Robot can be servoed or non-servoed. (See INTELLIGENT ROBOT)

SERVO-CONTROLLED ROBOT

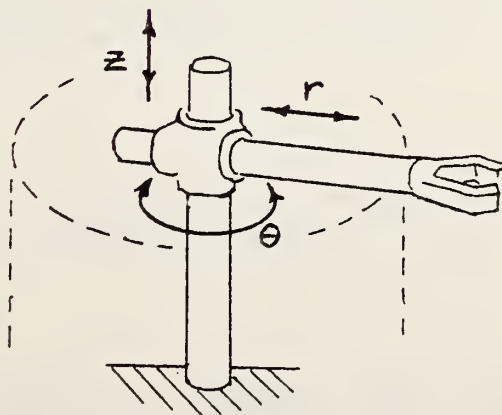
A robot driven by servomechanisms, i.e. motors whose driving signal is a function of the difference between commanded position and/or rate and measured actual position and/or rate. Such a robot is capable of stopping at or moving through a practically unlimited number of points in executing a programmed trajectory.

OPEN LOOP ROBOT

A robot which incorporates no feedback, i.e. no means of comparing actual output to commanded input of position or rate.

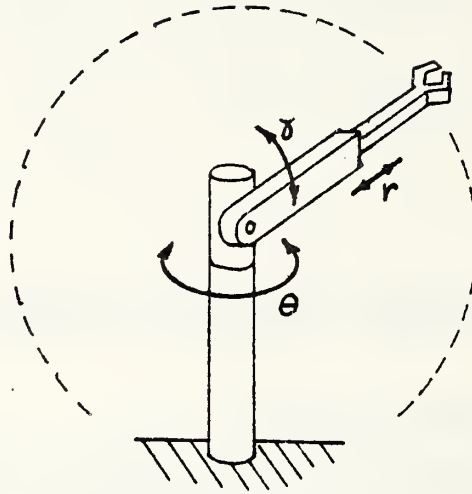
CYLINDRICAL COORDINATE ROBOT

A robot whose manipulator arm degrees of freedom are defined primarily by cylindrical coordinates.



SPHERICAL COORDINATE ROBOT

A robot whose manipulator arm degrees of freedom are defined primarily by spherical coordinates.



2. GENERAL ROBOTICS TERMS

PROGRAMMABLE MANIPULATOR

A device which is capable of manipulating objects by executing a stored program resident in its memory.

TELEOPERATOR

A device having sensors and actuators for mobility and/or manipulation, remotely controlled by a human operator. A teleoperator allows an operator to extend his sensory-motor function to remote or hazardous environments.

MASTER-SLAVE MANIPULATOR

A class of teleoperator having geometrically isomorphic "master and slave" arms. The master is held and positioned by a person; the slave duplicates the motions, sometimes with a change of scale in displacement or force.

BILATERAL MANIPULATOR

A master-slave manipulator with symmetric force reflection where both master and slave arms have sensors and actuators such that in any degree of freedom a positional error between the master and slave results in equal and opposing forces applied to the master and the slave arms.

AUTOMATION

The theory, art, or technique of making a process automatic, self moving, or self-controlling.

LEVEL OF AUTOMATION

The degree to which a process has been made automatic. Relevant to the level of automation are questions of automatic failure recovery, the variety of situations which will be automatically handled, and the situation under which manual intervention or action by humans is required.

HIERARCHY

A relationship of elements in a structure divided into levels, with those at higher levels having priority or precedence over those at lower levels. (See control hierarchy and sensory hierarchy.)

CONTROL HIERARCHY

A relationship of control elements whereby the results of higher level control elements are used to command lower level elements.

SENSORY HIERARCHY

A relationship of sensory processing elements whereby the results of lower level elements are utilized as inputs by higher level elements.

ADAPTABLE

Capable of making self directed corrections. In a robot this is often accomplished with the aid of visual, force or tactile sensors.

See definition 2 of "Flexible".

ARCHITECTURE

Physical, and logical structure of a computer or manufacturing process.

PROGRAMMABLE

Capable of being instructed to operate in a specified manner or of accepting setpoints or other commands from a remote source.

REDUNDANCY

Duplication of information or devices in order to improve reliability.

FLEXIBLE

1. Pliable or capable of bending. In robot mechanisms this may be due to joints, links, or transmission elements. Flexibility allows the endpoint of the robot to sag or deflect under load and to vibrate as a result of acceleration or deceleration.

2. Multipurpose; adaptable; capable of being redirected, retrained or used for new purposes. Refers to the reprogrammability or multi-task capability of robots.

MANIPULATION

The operation of grasping and moving an object.

MODULAR

Made up of subunits which can be combined in various ways.

In robots, a robot constructed from a number of interchangeable subunits each of which can be one of a range of sizes or have one of several possible motion styles (prismatic, cylindrical, etc.) and number of axes.

"Modular design" permits assembly of products, or software or hardware from standardized components.

INTERFACES

A shared boundary. An interface might be a mechanical or electrical connection between two devices; it might be a portion of computer storage accessed by two or more programs; or it might be a device for communication to or from a human operator.

3. RELATED TECHNICAL AREAS

ARTIFICIAL INTELLIGENCE

The ability of a device to perform functions that are normally associated with human intelligence, such as reasoning, planning, problem solving, pattern recognition, perception, cognition, understanding, and learning.

PATTERN RECOGNITION

Description or classification of pictures or other data structures into a set of classes or categories; a subset of the subject artificial intelligence.

GROUP TECHNOLOGY

A system for coding parts based on similarities in geometrical shape or other characteristics of the parts.

The grouping of parts into families based on similarities in their production so that the parts of a particular family could then be processed together.

PART CLASSIFICATION

A coding scheme, typically involving four or more digits, which specifies a discrete product as belonging to a part family.

FLEXIBLE MANUFACTURING SYSTEMS

An arrangement of machines (usually numerical control machining centers with tool changers) interconnected by a transport system. The transporter carries work to the machines on pallets or other interface units so that work-machine registration is accurate, rapid and automatic. A central computer controls both machines and transport system. Flexible manufacturing systems sometimes process several different workpieces at any one time.

ADAPTIVE CONTROL

A control method in which control parameters are continuously and automatically adjusted in response to measured process variables to achieve better performance.

4. MANUFACTURING SYSTEMS

BATCH MANUFACTURING

The production of parts in discrete runs, or batches, interspersed with other production operations or runs of other parts.

MASS PRODUCTION

The large scale production of parts in a continuous process uninterrupted by the production of other parts.

JOB SHOP

A discrete parts manufacturing facility characterized by a mix of products of relatively low volume production in batch lots.

COMPUTER AIDED DESIGN (CAD)

The use of a computer to assist in the creation or modification of a design.

COMPUTER AIDED MANUFACTURE (CAM)

The use of computer technology in the management, control, and operation of manufacturing.

NUMERICAL CONTROL (NC)

A technique that provides for the automatic control of a machine tool from information prerecorded in symbolic form representing every detail of the machining sequence.

COMPUTER NUMERICAL CONTROL (CNC)

The use of a dedicated mini or microcomputer to implement the numerical control function. Uses local data input from devices such as paper tape, magnetic tape cassette or floppy disk.

DISTRIBUTED NUMERICAL CONTROL (DNC)

The use of a computer for distributing part program data via data lines to a plurality of remote NC machine tools.

WORK STATION

A manufacturing unit consisting of one or more numerically controlled machine tools serviced by a robot.

CELL

A manufacturing unit consisting of two or more work stations and the materials transport mechanisms and storage buffers which interconnect them.

CENTER

A manufacturing unit consisting of two or more cells and the materials transport and storage buffers which interconnect them.

FACTORY

A manufacturing unit consisting of two or more centers and the materials transport, storage buffers, and communications which interconnect them.

5. MECHANICAL HARDWARE

5.1 STRUCTURE

ARM

An interconnected set of links and powered joints comprising a manipulator which supports or moves a wrist and hand or end effector.

ELBOW

The joint which connects the upperarm and forearm.

FOREARM

That portion of a jointed arm which is connected to the wrist.

UPPERARM

That portion of a jointed arm which is connected to the shoulder.

HAND

A device attached to the wrist having a mechanism with closing jaws or other means to grasp objects.

WRIST

A set of rotary joints between the arm and hand which allow the hand to be oriented to the workpiece.

BASE

The platform or structure to which the shoulder of a robot arm is attached; the end of a kinematic chain of arm links and joints opposite to that which grasps or processes external objects.

SHOULDER

The joint, or pair of joints, which connect the arm to the base.

JOINT

A rotational or translational degree-of-freedom in a manipulator system.

END EFFECTOR

An actuator, gripper, or mechanical device attached to the wrist of a manipulator by which objects can be grasped or otherwise acted upon.

GRIPPER

A device by which a robot may grasp and hold external objects.

5.2 ACTUATORS

ACTUATOR

A motor or transducer which converts electrical, hydraulic or pneumatic energy to effect motion of the robot.

TRANSDUCER

A device which converts one form of energy into another form of energy.

POWER CYLINDER

A linear mechanical actuator consisting of a piston in a cylindrical volume and driven by high pressure hydraulic or pneumatic fluid.

HYDRAULIC MOTOR

An actuator consisting of interconnected valves and pistons or vanes which converts high pressure hydraulic or pneumatic fluid into mechanical shaft translation or rotation.

INDUCTION MOTOR

An alternating current motor in which torque is produced by the reaction between a varying or rotating magnetic field that is generated in stationary field magnets and the current that is induced in the coils or circuits of the rotor.

SERVOMECHANISM

An automatic control mechanism consisting of a motor driven by a signal which is a function of the difference between commanded position and/or rate and measured actual position and/or rate.

SERVOVALVE

A transducer whose input is a low-energy signal and whose output is a higher energy fluid flow which is proportional to the low-energy signal.

SOLENOID

A cylindrical coil of wire surrounding a movable core which, when energized, sets up a magnetic field and draws in the core.

STEPPING MOTOR

An electric motor whose windings are arranged in such a way that the armature can be made to step in discrete rotational increments (typically 1/200 th of a revolution) when a digital pulse is applied to an accompanying "driver" circuit. The armature displacement will stay locked in this angular position independent of applied torque, up to a limit.

5.3 POWER AND TRANSMISSION

CABLE DRIVE

Transmission of power from an actuator to a remote mechanism by means of a flexible cable and pulleys.

TAPE DRIVE

Transmission of power from an actuator to a remote mechanism by means of flexible tape and pulleys.

CHAIN DRIVE

Transmission of power from an actuator to a remote mechanism by means of a flexible chain and mating toothed sprocket wheels.

LEAD SCREW

A precision machine screw which, when turned, drives a sliding nut or mating part in translation.

STOP

A mechanical constraint or limit on some motion which can be set to stop the motion at a desired point.

LIMIT SWITCH

An electrical switch which is actuated when a moving part reaches a specified limit, thereby causing the motion to cease.

6. PERFORMANCE MEASURES

ACCURACY

Quality, state, or degree of conformance to a recognized standard or specification.

Degree to which actual position corresponds to desired or commanded position.

CALIBRATION

To determine the deviation from a standard so as to ascertain the proper corrections.

DRIFT

The tendency of a system's response to gradually move away from the desired response.

DYNAMIC ACCURACY

Degree of conformance to the true value when relevant variables are changing with time.

Degree to which actual motion corresponds to desired or commanded motion.

FAIL SAFE

Failure of a device without danger to personnel or damage to product or plant facilities.

FAIL SOFT

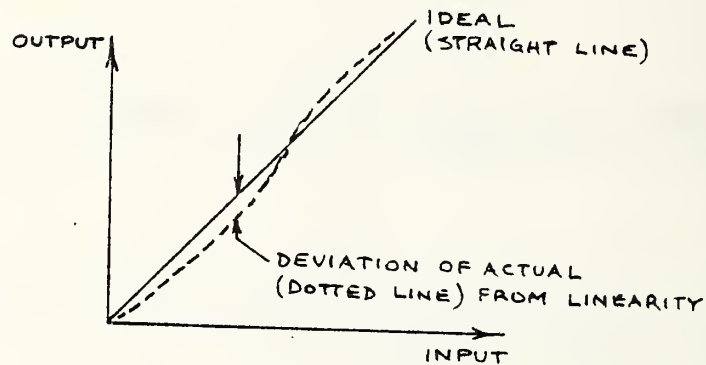
Failure in performance of some component part of a system without immediate major interruption or failure of performance of the system as a whole and/or sacrifice in quality of the product.

GRACEFUL DEGRADATION

Decline in performance of some component part of a system without immediate and significant decline in performance of the system as a whole and/or decline in the quality of the product.

LINEARITY

The degree to which input-output is a directly proportional relationship.



The degree to which a motion intended to be in a straight line conforms to a straight line.

LOAD

In physics, the external force applied to a body, or the energy required; also, the act of applying such force or requiring such energy.

LOAD CAPACITY

The maximum weight or mass of a material that can be handled by a machine or process without degradation of performance specifications or failure of the equipment.

LONG TERM REPEATABILITY

Closeness of agreement of position movements, repeated under the same conditions during a long time interval, to the same location.

MAXIMUM SPEED

The greatest rate at which an operation can be accomplished according to some criterion of satisfaction.

The greatest velocity of movement of a tool or end effector which can be achieved in producing a satisfactory result.

MEAN-TIME-BETWEEN-FAILURES (MTBF)

The average time that a device will operate before failure.

MEAN-TIME-TO-REPAIR (MTTR)

The average time needed to repair or service a device after failure.

NET LOAD CAPACITY

The additional weight or mass of a material that can be handled by a machine or process without failure over and above that required for a container, pallet or other device which necessarily accompanies the material.

PAYLOAD

The maximum weight or mass of a material that can be handled satisfactorily by a machine or process in normal and continuous operation.

PERFORMANCE

The quality of behavior.

The degree to which a specified result is achieved.

A quantitative index of such behavior or achievement, such as speed, power, or accuracy.

PLAYBACK ACCURACY

Difference between a position command recorded in an automatic control system and that actually produced at a later time when the recorded position is used to execute control.

Difference between actual position response of an automatic control system during a programming or teaching run and that corresponding response in a subsequent run.

PRECISION

The standard deviation, or root-mean-squared deviation of values around their mean.

RATED LOAD CAPACITY

A specified weight or mass of a material that can be handled by a machine or process which allows for some margin of safety relative to the point of expected failure.

RELIABILITY

The probability that a device will function without failure over a specified time period or amount of usage.

REPEATABILITY

Closeness of agreement of repeated position movements, under the same conditions, to the same location.

RESOLUTION

The least interval between two adjacent discrete details which can be distinguished from one another.

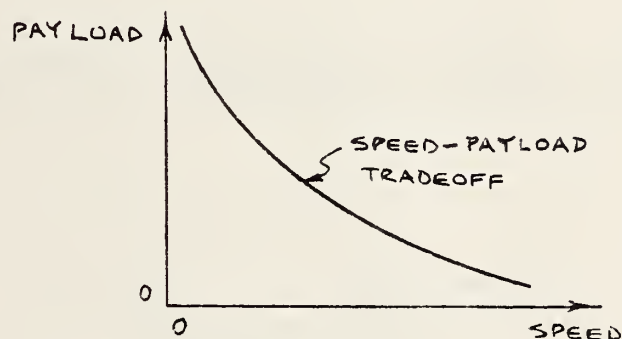
The smallest increment of distance that can be read and acted upon by an automatic control system.

SHORT-TERM REPEATABILITY

Closeness of agreement of position movements, repeated under the same conditions during a short time interval, to the same location.

SPEED-PAYLOAD TRADEOFF

The relationship between corresponding values of maximum speed and payload with which an operation can be accomplished to some criterion of satisfaction, and with all other factors remaining the same. See Maximum speed and Payload.



SPEED-RELIABILITY TRADEOFF

The relationship between corresponding values of maximum speed and reliability with which an operation can be accomplished to some criterion of satisfaction, and with all other Factors remaining the same. See Maximum speed and Reliability

SPRINGBACK

The deflection of a body when external load is removed. Usually refers to deflection of the end effector of a manipulator arm.

STATIC ERROR

Deviation from true value when relevant variables are not changing with time.

Difference between actual position response and position desired or commanded of an automatic control system as determined in the steady state, i.e., when all transient responses have died out.

STEADINESS

Relative absence of high frequency vibration or jerk.

STRENGTH

Same as load capacity.

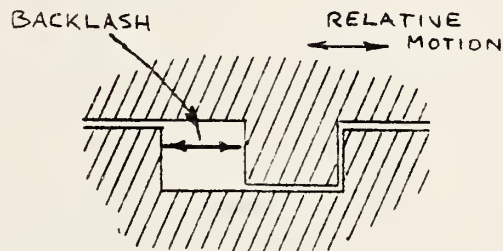
7. STATICS AND KINEMATICS

AZIMUTH

Direction of a straight line to a point in a horizontal plane, expressed as the angular distance from a reference line, such as the observer's line of view.

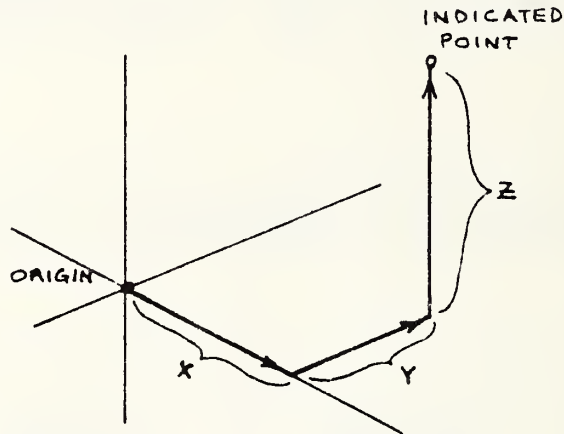
BACKLASH

Free play in a power transmission system, such as a gear train, resulting in a characteristic form of hysteresis.



CARTESIAN COORDINATE SYSTEM

A coordinate system whose axes or dimensions are three intersecting perpendicular straight lines and whose origin is the intersection.



CENTER OF GRAVITY

That point in a rigid body at which the entire mass of the body could be concentrated and produce the same gravity resultant as that for the body itself.

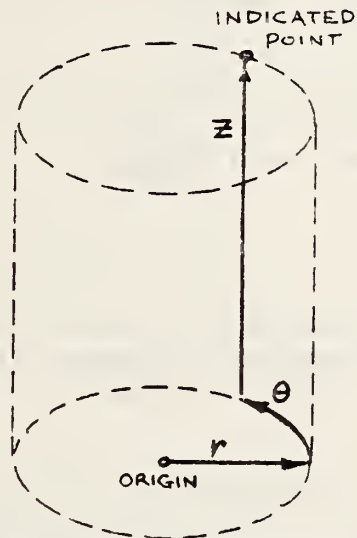
COMPLIANCE

The quality or state of bending or deforming to stresses within the elastic limit.

The amount of displacement per unit of applied force.

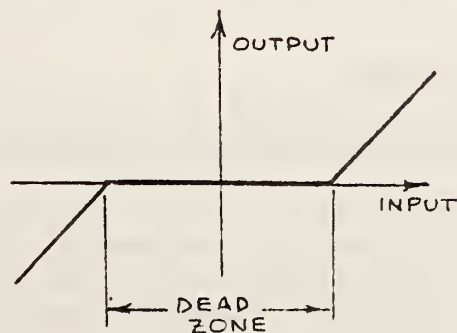
CYLINDRICAL COORDINATE SYSTEM

A coordinate system which defines the position of any point in terms of an angular dimension, a radial dimension, and a height from a reference plane.



DEAD ZONE

A range within which a non-zero input causes no output.



DEGREE OF FREEDOM

One of a limited number of ways in which a point or a body may move or in which a dynamic system may change, each way being expressed by an independent variable and all required to be specified if the physical state of the body or system is to be completely defined.

DISTAL

Away from the base, toward the end effector of the arm.

DROOP

Same as static load deflection.

ELEVATION

Direction of a straight line to a point in a vertical plane, expressed as the angular distance from a reference line, such as the observer's line of view.

END POINT RIGIDITY

The resistance of the hand, tool or end point of a manipulator arm to motion under applied force.

EXTENSION

A linear motion in the direction of travel of the sliding motion mechanism, or an equivalent linear motion produced by two or more angular displacements of a linkage mechanism.

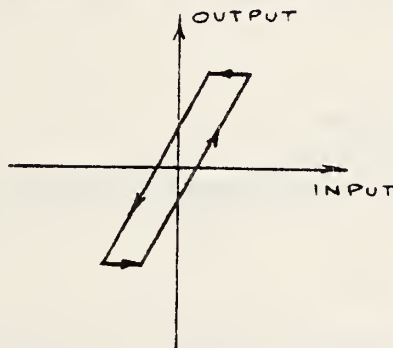
FIXED COORDINATE SYSTEM

A coordinate system fixed in time and space.

HYSTERESIS

The lagging of a physical response of a body behind its cause.

Asymmetry of the force/displacement relationship in one direction compared to other.



JOINT SPACE

The space defined by a vector whose components are the angular or translational displacement of each joint of a multi-degree-of-freedom linkage relative to a reference displacement for each such joint.

LINEAR

The quality of an input-output relationship in which there is direct proportionality.

LOAD DEFLECTION

The difference in position of some point on a body between a non-loaded and an externally loaded condition.

The difference in position of a manipulator hand or tool, usually with the arm extended, between a non-loaded condition (other than gravity) and an externally loaded condition. Either or both static and dynamic (inertial) loads may be considered.

PAN

Orientation of a view, as with a video camera, in azimuth.

Motion in the azimuth direction.

PITCH

The angular rotation of a moving body about an axis perpendicular to its direction of motion and in the same plane as its top side.

POLAR COORDINATE SYSTEM

Same as SPHERICAL COORDINATE SYSTEM.

PRONATION

Orientation or motion toward a position with the back, or protected side, facing up or exposed.

PROXIMAL

Close to the base, away from the end effector of the arm.

RECTANGULAR COORDINATE SYSTEM

Same as cartesian coordinate system but applied to points in a plane (only two axes used).

RELATIVE COORDINATE SYSTEM

A coordinate system whose origin moves relative to world or fixed coordinates.

REMOTE CENTER COMPLIANCE (RCC)

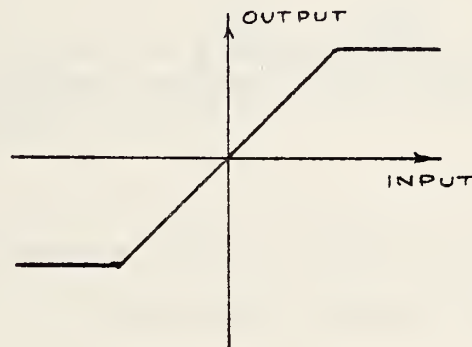
A compliant device used to interface a robot or other mechanical workhead to its tool or working medium. The RCC allows a gripped part to rotate about its tip or to translate without rotating when pushed laterally at its tip. The RCC thus provides general lateral and rotational "float" and greatly eases robot or other mechanical assembly in the presence of errors in parts, jigs, pallets and robots. It is especially useful in performing very close clearance or interference insertions.

ROLL

The angular displacement of a moving body around the principal axis of its motion.

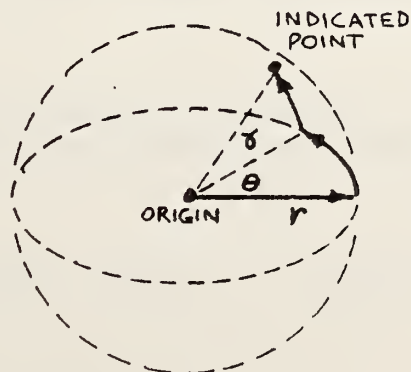
SATURATION

The extremes of operating range wherein the output is constant regardless of changes in input.



SPHERICAL COORDINATE SYSTEM

A coordinate system, two of whose dimensions are angles, the third being a linear distance from the point of origin. These three coordinates specify a point on a sphere.



STATIC DEFLECTION

Load deflection considering only static loads, i.e., excluding inertial loads. Sometimes static deflection is meant to include the effects of gravity loads.

STIFFNESS

The amount of applied force per unit of displacement of a compliant body.

SUPINATION

Orientation or motion toward a position with the front, or unprotected side, facing up or exposed.

TILT

Orientation of a view, as with a video camera, in elevation.

Motion in the elevation direction.

TRANSLATION

Movement of a body such that all axes remain parallel to what they were, i.e. without rotation.

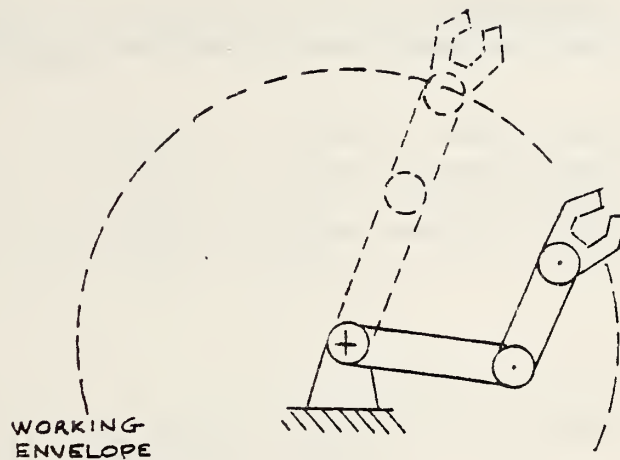
WINDUP

Colloquial term describing the twisting of a shaft under torsional load, so called because the twist usually unwinds, sometimes causing vibration or other undesirable effects.

WORKING ENVELOPE

The set of points representing the maximum extent or reach of

the robot hand or working tool in all directions.



WORKING RANGE

All positions within the working envelope.

The range of any variable within which the system normally operates.

WORKING SPACE OR VOLUME

The physical space bounded by the working envelope in physical space.

WORLD COORDINATES

A coordinate system referenced to earth, or a shop floor.

TWIST

Rotational displacement around a reference line; same as roll.

YAW

The angular displacement of a moving body about an axis which is perpendicular to the line of motion and to the top side of the body.

8. DYNAMICS AND CONTROL

ACTIVE ACCOMMODATION

Integration of sensors, control, and robot motion to achieve alteration of a robot's preprogrammed motions in response to sensed forces. Used to stop a robot when forces reach set levels, or to perform force feedback tasks like insertions, door opening and edge tracing.

ANALOG CONTROL

Control involving analog signal processing devices (electronic, hydraulic, pneumatic, etc.)

BANDWIDTH

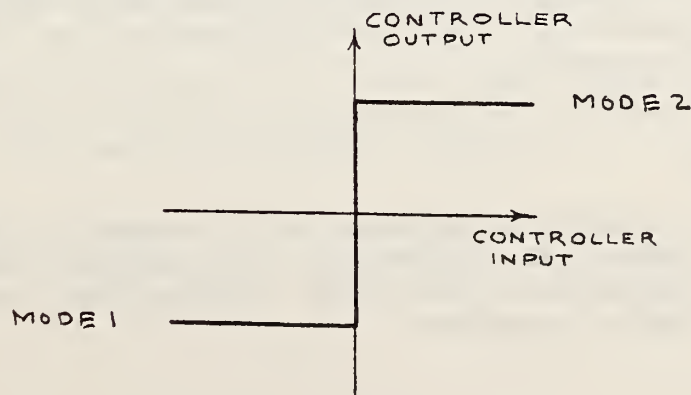
The range of frequencies contained in a time function.

The range of frequencies to which a dynamic system will respond.

The range of frequencies which a communication channel will pass.

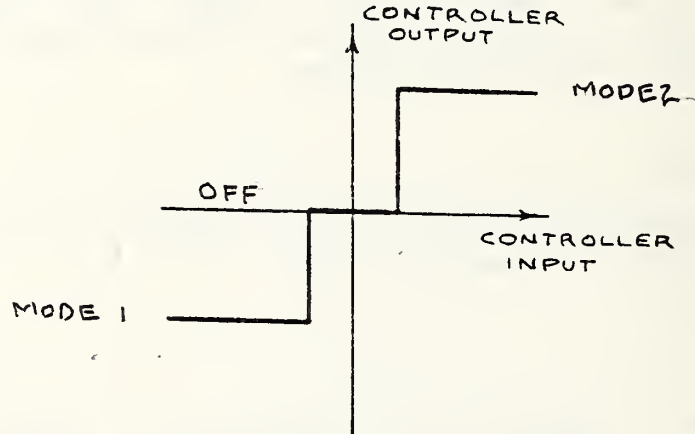
BANG-BANG CONTROL

A binary control system which rapidly changes from one mode or state to the other (in motion systems, this applies to direction only).



BANG-BANG-OFF CONTROL

A ternary control system which rapidly changes from one mode or state to another, or does nothing. (In motion systems, this applies to direction only).



BREAKAWAY FORCE

Same as static friction, though this term implies more strongly that the resistive force is not constant as the relative velocity increases.

CLOSED-LOOP CONTROL

Control achieved by feedback, i.e., by measuring the degree to which actual system response conforms to desired system response and utilizing the difference to drive the system into conformance.

COMPENSATION

Logical operations employed in a control scheme to counteract dynamic lags or otherwise to modify the transformation between measured signals and controller output to produce prompt stable response.

COMPUTED PATH CONTROL

A control scheme wherein the path of the manipulator endpoint is computed to achieve a desired result in conformance to a given criterion, such as an acceleration limit, a minimum time, etc.

COMPUTER CONTROL

Control involving one or more electronic digital computers.

CONTINUOUS PATH CONTROL

A control scheme whereby the inputs or commands specify every point along a desired path of motion.

CONTROL

The process of making a variable or system of variables conform to what is desired.

A device to achieve such conformance automatically.

A device by which a person may communicate his commands to a machine.

CONTROLLER

A device to achieve control.

COORDINATED AXIS CONTROL

Control wherein the axes of the robot arrive at their respective endpoints simultaneously, giving a smooth appearance to the motion.

Control wherein the motions of the axes are such that the endpoint moves along a prespecified type of path (line, circle, etc). Also called endpoint control.

DAMPING

The absorption of energy from a moving body for the purpose of controlling oscillatory vibrations. This term has an electrical analog.

DERIVATIVE CONTROL

Control scheme whereby the actuator drive signal is proportional to the time derivative of the difference between the input (desired output) and the measured actual output.

DIGITAL CONTROL

Control involving digital logic devices which may or may not be complete digital computers.

DISTRIBUTED CONTROL

A control technique whereby portions of a single control process are located in two or more places.

HIERARCHICAL CONTROL

A distributed control technique in which the controlling processes are arranged in a hierarchy. See Hierarchy.

DYNAMIC RANGE

The extent of any variable of a system.

ENDPOINT CONTROL

Any control scheme in which only the motion of the manipulator end point may be commanded and the computer can command the actuators at the various degrees of freedom to achieve the desired result.

ERROR SIGNAL

The difference between desired response and actual response.

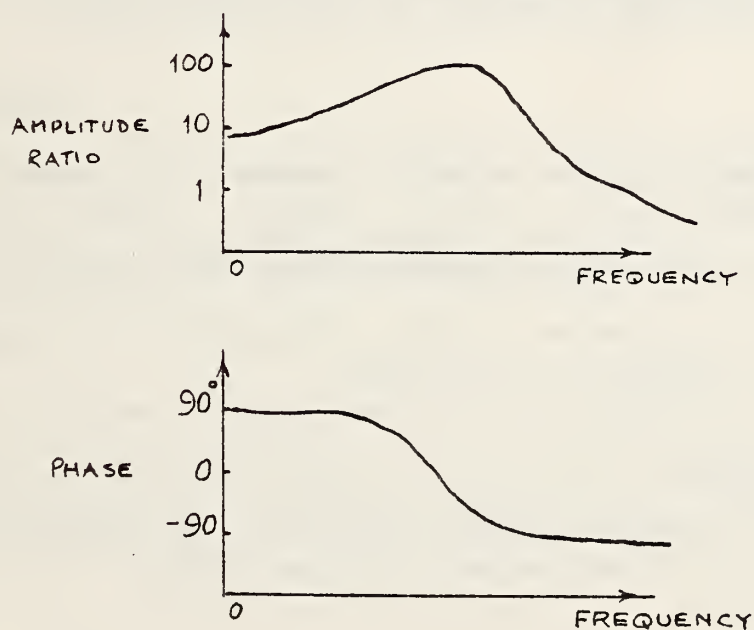
FEEDBACK

A signal derived from the output which is used to drive the control actuator.

FREQUENCY RESPONSE

The output of a system with a periodic input. Frequency response may be defined in terms of the fourier coefficients or the gain and phase at each multiple of the period.

The characterization of system output to a continuous spectral input according to a continuous plot of gain and phase as a function of frequency.



FRICTION

The resistive forces resulting from two bodies sliding relative to one another.

INERTIA

The tendency of a mass at rest to remain at rest, and of a mass in motion to remain in motion.

The Newtonian property of a physical mass that a force is required to change the velocity, proportional to the mass and the time rate of change of velocity.

INTEGRAL CONTROL

Control scheme whereby the signal which drives the actuator equals the time integral of the error signal.

LAG

The tendency of the dynamic response of a physical system to be delayed.

The phase difference between input and response sinusoids.

Any time parameter which characterizes the delay of a response relative to an input.

LEARNING CONTROL

A control scheme whereby experience is automatically used to change control parameters or algorithms.

MODERN CONTROL

A general term used to encompass both the description of systems in terms of state variables and canonical state equations, and the ideas of optimal control.

MULTIPROCESSOR CONTROL

A control scheme which employs more than one central processing unit in simultaneous parallel computation.

NOISE

A spurious, unwanted or disturbing signal.

OBJECTIVE FUNCTION

An equation defining a scalar quantity (to be minimized under given constraints by an optimal controller) in terms of such performance variables as error, energy and time. The objective function defines a tradeoff relation between the variables.

OPEN LOOP CONTROL

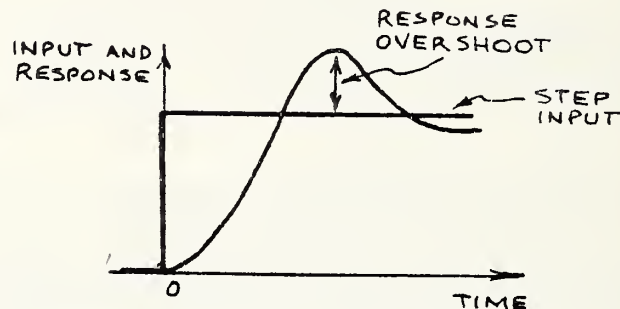
Control achieved by driving control actuators with a sequence of preprogrammed signals without measuring actual system response and closing the feedback loop.

OPTIMAL CONTROL

A control scheme whereby the system response to a commanded input is optimal according to a specified objective function or criterion of performance, given the dynamics of the process to be controlled and the constraints on measuring.

OVERSHOOT

The degree to which a system response to a step change in reference input goes beyond the desired value.



PASSIVE ACCOMMODATION

Compliant behavior of a robot's endpoint in response to forces exerted on it. No sensors, controls or actuators are involved. The remote center compliance provides this in a coordinate system acting at the tip of a gripped part.

POINT-TO-POINT CONTROL

A control scheme whereby the inputs or commands specify only a limited number of points along a desired path of motion. The control system determines the intervening path segments.

POSITION CONTROL

Control by a system in which the input command is the desired position of a body.

PROCESS CONTROL

Control of the product and associated variables of processes (such as oil refining, chemical manufacture, water supply, and electrical power generation) which are continuous in time.

PROPORTIONAL CONTROL

Control scheme whereby the signal which drives the actuator is monotonically related to the difference between the input command (desired output) and the measured actual output.

PROPORTIONAL-INTEGRAL-DERIVATIVE CONTROL (PID)

Control scheme whereby the signal which drives the actuator equals a weighted sum of the difference, time integral of the difference, and time derivative of the difference between the input (desired output) and the measured actual output.

RATE CONTROL

Control system in which the input is the desired velocity of the controlled object.

SENSORY CONTROL

Control of a robot based on sensor readings. Several types can be employed.

Sensors used in threshold tests to terminate robot activity or branch to other activity.

Sensors used in a continuous way to guide or direct changes in robot motions. (See accommodation.)

Sensors used to monitor robot progress and to check for task completion or unsafe conditions.

Sensors used to retrospectively update robot motion plans prior to the next cycle.

RESOLVED MOTION RATE CONTROL

A control scheme whereby the velocity vector of the endpoint of a manipulator arm is commanded and the computer determines the joint angular velocities to achieve the desired result.

Coordination of a robot's axes so that the velocity vector of the endpoint is under direct control. Motion in the coordinate system of the endpoint along specified directions or trajectories (line, circle, etc.) is possible. Used in manual control of manipulators and as a computational method for achieving programmed coordinate axis control in robots.

SETTLING TIME

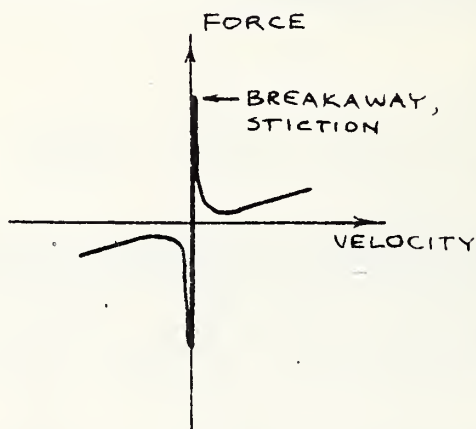
The time for a damped oscillatory response to decay to within some given limit.

SLEW RATE

The maximum rate at which a system can follow a commanded motion.

STATIC FRICTION

The force required to initiate sliding or rolling motion between two contacting bodies.



STEADY STATE

General term referring to a value which does not change with time.

Response of a dynamic system in accordance with its characteristic behavior, i.e., after any transient response has died out; the steady state response may be either a constant or periodic signal.

STICTION

Same as static friction.

SUPERVISORY CONTROL

A control scheme whereby a person or computer monitors and intermittently reprograms, sets subgoals or adjusts control parameters of a lower level automatic controller, while the lower level controller performs the control task continuously in real time.

TIME CONSTANT

Any of a number of parameters of a dynamic function which have units of time.

Parameters which particularly characterize the temporal properties of a dynamic function, such as the period of a periodic function or the inverse of the initial slope of a first order exponential response to a step.

TRACKING

Continuous position control response to a continuously changing input.

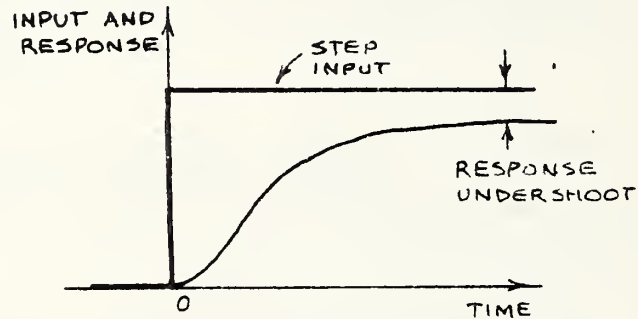
TRANSIENT

A value which changes, decays, or disappears in time.

Momentary response of a dynamic system to a rapid input variation such as a step or a pulse.

UNDERSHOOT

The degree to which a system response to a step change in reference input falls short of the desired value.



VISCOUS FRICTION

The resistive force on a body moving through a fluid.

Ideally, a resistive force proportional to relative velocities of a body and a fluid.

9. SENSORY FEEDBACK

9.1 MACHINE VISION

VIDECON

An electron tube device used in a television camera to convert an optical image into an electrical signal through the scanning of an electron beam over a photo sensitive window.

SOLID STATE CAMERA

A television camera which has an array of photosensitive semiconductor elements to produce a TV output.

CID CAMERA

A solid state television camera which uses charge injection device (CID) technology.

CCD CAMERA

A solid state television camera which uses charge coupled device (CCD) technology.

LINEAR ARRAY CAMERA

A solid state television camera which has only one row of photosensitive elements.

MATRIX ARRAY CAMERA

A solid state television camera which has a rectangular array of photosensitive elements.

STRUCTURED LIGHT

Illumination which is projected in a particular geometrical pattern.

ACTIVE ILLUMINATION

Light which is controlled in intensity, direction, or projection pattern by a set of commands or signals from a controlling source.

FRAME BUFFER

A device which can store a television picture (or frame) for later processing.

BINARY PICTURE

A video picture with only two shades of brightness (white and black).

GREY SCALE PICTURE

A video picture with many shades of brightness.

SEGMENTATION

The dividing up of a picture into regions according to some property of the picture within the regions or along the region boundaries.

TEMPLATE MATCHING

The comparison of a picture, or other data set, against a stored pattern, or template.

RUN-LENGTH ENCODING

A method of denoting the length of a string of elements each of which has the same property. Usually used in denoting the length of strings of picture elements with the same brightness.

THRESHOLDING

The comparison of an element value, such as pixel brightness, against a set point value, or threshold. All elements whose values are above threshold are set to the binary value "1". All elements below threshold are set to the binary value "0".

PIXEL

Contraction for picture element. A light sensitive point in an array of such points which comprise a picture.

9.2 NON-IMAGING SENSORS

SENSOR

A transducer whose input is a physical phenomenon and whose output is a quantitative measure of that physical phenomenon.

SMART SENSOR

A sensing device whose output signal is contingent upon mathematical or logical operations which are based upon internal data or additional sensing devices.

TACTILE SENSOR

A transducer which is sensitive to touch.

RESOLVER

A transducer which converts rotary or linear mechanical position into an analog electrical signal by means of the interaction of electromagnetic fields between the movable and the stationary parts of the transducer.

ENCODER

A transducer used to convert angular or linear position or velocity into electrical signals.

A device used to convert one form of information into another.

SHAFT ENCODER

An encoder used to measure shaft angle position.

TACHOMETER

A rotational velocity sensor.

SYNCHRO

A shaft encoder based upon differential inductive coupling between an energized rotor coil and field coils positioned at different shaft angles.

CONTACT SENSOR

A device capable of sensing mechanical contact.

POTENTIOMETER

An encoder based upon tapping the voltage at a point along a continuous electrical resistive element.

CONDUCTIVE RUBBER

A material consisting of carbon or silver spheres suspended in rubber, whose electrical resistance decreases gradually as it is mechanically compressed.

STRAIN GAGE

A sensor which when cemented to elastic materials measures very small amounts of stretch by the change in its electrical resistance. When used on materials with high modulus of elasticity strain gages become force sensors.

STRAIN GAGE ROSETTE

Multiple strain gages cemented in a two or three dimensional geometric pattern such that independent measurements of the strain on each can be combined to yield a vector measurement of strain or force.

PROXIMITY SENSOR

A device which senses that an object is only a short distance (e.g., a few inches or feet) away, and/or measures how far away it is. Proximity sensors work on the principles of triangulation of reflected light, lapsed time for reflected sound, or intensity induced eddy currents, magnetic fields, back pressure from air jets, and others.

PIEZO ELECTRIC

The property of certain crystalline salts to produce an electrical charge on the surface of the crystal as a function of mechanical pressure.

10. COMPUTER AND CONTROL HARDWARE

CONTROLLER

An information processing device whose inputs are both desired and measured position velocity or other pertinent variables in a process and whose outputs are drive signals to a controlling motor or actuator.

A communication device through which a person introduces commands to a control system.

A person who does the same.

PROGRAMMABLE CONTROLLER

A controller whose algorithm for computing control outputs is programmable.

CENTRAL PROCESSING UNIT (CPU)

The part of a computer that executes instructions and operates on data.

MICROPROCESSOR

The principal processing element of a microcomputer constructed as a single integrated circuit.

MICROCOMPUTER

A computer which uses a microprocessor as its basic element.

MULTIPROCESSOR

A computer or network of computers that can execute several programs concurrently under integrated control.

HOST COMPUTER

The primary or controlling computer in a multiple computer operation.

MEMORY

A device into which data can be entered, in which it can be stored, and from which it can be retrieved at a later time.

MAGNETIC CORE MEMORY

A configuration of magnetic beads strung on current carrying conductors which retain magnetic polarization for the purpose of storing and retrieving data.

READ ONLY MEMORY (ROM)

A data storage device generally used for a control program, whose content is not alterable by normal operating procedures.

PROGRAMMABLE READ ONLY MEMORY (PROM)

A read only memory which can be modified by special electronic procedures.

READ AND WRITE MEMORY (RAM)

A data storage device which can be both read from and written into (i.e., modified) during the normal execution of a program.

METAL-OXIDE SEMICONDUCTOR (MOS)

A semiconductor manufacturing technology used to produce large scale integrated (LSI) circuit logic components.

COMPLEMENTARY METAL-OXIDE SEMICONDUCTOR (CMOS)

An integrated circuit logic family characterized by very low power dissipation, moderate circuit density per chip, and moderate speed of operation.

INTEGRATED CIRCUIT (IC)

An electronic circuit packaged in a small unit ranging in complexity and function from simple logic gates to microprocessors, amplifiers, and analog-digital converters. The circuit may be constructed on a single semiconductor substrate (a configuration called monolithic) or several such circuits can be connected in one package (called a hybrid).

LARGE SCALE INTEGRATION (LSI)

A classification for a scale of complexity of an integrated electronic circuit chip. Other classes are very large scale integration (VLSI), medium scale integration (MSI) and small scale integration (SSI).

SILICON CONTROLLED RECTIFIER (SCR)

A binary solid-state electronic switching device generally used in controlling high-power loads such as electric motors, solenoids, etc.

OPERATIONAL AMPLIFIER

A high gain electronic circuit, used in a variety of amplification applications. Can be connected to provide the integral of an input. Often used in analog computers.

MULTIPLEXER

A hardware device which allows communication of multiple signals over a single channel by sequential sampling.

ANALOG-TO-DIGITAL CONVERTER (A/D)

A device which transforms an analog signal into a digital quantity.

DIGITAL-TO-ANALOG CONVERTER (D/A)

A device which transforms a digital quantity into an analog signal.

PERIPHERAL DEVICE

Any piece of computer equipment, apart from the central processing unit and main memory system.

11. SOFTWARE

ACCESS TIME

The time interval between the instant when data are requested from a storage device and the instant when delivery is completed.

ASSEMBLER

A program that translates symbolic code into machine language and assigns memory locations for variables and constants.

ASSEMBLY LANGUAGE

A computer language, composed of brief symbolic expressions, which is translated by an assembler into a machine language. The language result (object code) from the assembler is a line-for-line translated version of the original.

BACKGROUND PROCESSING

The execution of lower priority programs when higher priority programs are not using the system resources. Contrast with Foreground Processing.

COMPILER

A program that converts a program written in a high level language (such as FORTRAN) into binary coded instructions that the machine can interpret.

BRANCHING

Changing of the normal sequential execution of statements in a program.

CONDITIONAL STATEMENT

A computer program step whose results depend upon whether certain tests or criteria are met.

CROSS-ASSEMBLER

A computer program to assemble language instructions into a form suitable for running on another computer.

DATA BASE

A collection of data relevant to a particular object or process which is organized in a systematic structure.

DEFAULT VALUE

A value which is used until a more valid value is found.

DIAGNOSTIC

Pertaining to the detection and isolation of a malfunction or mistake.

DOUBLE PRECISION

Pertaining to the use of two computer words to represent a number.

EDIT

To modify the form or format of data, e.g., to insert or delete characters.

EDITOR

A routine or mechanism which performs editing operations.

EXECUTE

To carry out an instruction or perform a routine.

FILE

A repository of organized information consisting of records, items or arrays, and data elements.

FIRMWARE

Programs loaded in read-only memory (ROM). Firmware is often a fundamental part of the system's hardware design as contrasted to software, which is not fundamental to the hardware operation.

FIXED POINT REPRESENTATION

A number system in which the position of the decimal point is fixed with respect to one end of the string of numerals, according to some convention.

FLOATING POINT REPRESENTATION

A number representation system in which each number is represented by a pair of numerals. One of the numerals represents the exponent of an implicit base. The other represents the most significant digits of the original number.

FOREGROUND PROCESSING

The execution of programs that have been designed to preempt the use of computing facilities. Usually a real-time program. (Contrast with Background Processing.)

HEXADECIMAL

Pertaining to a number system with a base of 16. The digits of the hexadecimal number system are 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, F.

HIGH-LEVEL LANGUAGE

Programming language that generates machine codes from problem or function oriented statements. ALGOL, FORTRAN, PASCAL and BASIC are four commonly used high-level languages. A single functional statement may translate into a series of instructions or subroutines in machine language, in contrast to a low-level (assembly) language in which statements translate on a one-for-one basis.

INSTRUCTION SET

The list of machine language instructions which a computer can perform.

INTERLOCK

To prevent a machine or device from initiating further operations until the operation in process is completed.

INTERPRETER

A program that translates and executes each source language expression before translating and executing the next one.

A routine which decodes instructions and produces a machine language routine to be executed at a later time.

INTERRUPT

To stop the normal processing of a computer for the purpose of input/output of data, or for making an inquiry or receiving a reply, or carrying out interactive processes or procedures.

LOOP

A sequence of instructions that is executed repeatedly until some specified condition is met.

MACHINE LANGUAGE

A language that is used directly by a machine.

MACRO

A sequence of instructions which is defined under a single name. Each time the macro is invoked, the sequence of instructions is generated.

MEMORY PROTECTION

An arrangement for preventing access to storage for either reading or writing or both.

MENU

A display of options on a terminal device for user selection.

MONITOR

Software, or firmware that observes, supervises, controls, or verifies the operations of a system.

OPERATING SYSTEM

Software which controls the execution of computer programs and which may provide scheduling, debugging, input-output control, accounting, computation, storage assignment, data management and related services.

PARALLEL PROCESSING

Concurrent or simultaneous execution of two or more operations in devices, such as multiple arithmetic or logic units.

PARITY CHECK

A test to determine whether the number of ones (or zeroes) in an array of binary digits is even or odd. Such parity checks are widely used for paper tapes, magnetic tapes and other computer memories.

REAL TIME

Pertaining to computation performed in synchronization with the related physical process.

REAL TIME CLOCK

A device that generates periodic signals used for synchronization.

A register or storage area whose contents change at regular intervals in such a way as to measure time.

SOURCE PROGRAM

A program, usually written in a high level language, which is the input to a compiler, assembler, or interpreter.

OBJECT PROGRAM

A program which is the output of a compiler or assembler.

12. OPERATOR INTERFACES

12.1 DISPLAYS

ANNUNCIATOR

A light or sound signal designed to attract attention.

CURSOR

A movable pointer, indicator or marker on a visual display.

CATHODE-RAY TUBE (CRT)

A device that presents data in visual form by means of a controlled electron beam impinging on a phosphorescent surface.

LIGHT EMITTING DIODE (LED)

A semiconductor device that gives off light when current passes through it.

LIQUID CRYSTAL DISPLAY (LCD)

A display device, consisting of liquid crystal material hermetically sealed between two glass plates, which changes its optical properties under the influence of electrical current. One type of LCD depends upon ambient light for its operation, while a second depends upon a backlighting source.

THERMOCHROMIC DISPLAY

A display device consisting of materials which change to different colors when heated to different temperatures.

STORAGE TUBE

A CRT display device which retains a graphic image of a set of written signals until cleared or reset.

SCROLL

A graphic display technique whereby the generation of a new line of alphanumeric text at the bottom (or top) of a display screen automatically regenerates all other lines of text one line higher (or lower) than before, deleting the top (or bottom) line when it reaches the upper (or lower) limit of the display.

12.2 PROGRAMMING TECHNIQUES

ANALOGIC CONTROL

Pertaining to control by communication signals which are physically or geometrically isomorphic to the variables being controlled, usually by a human operator.

A device for effecting such control. Compare to Symbolic Control.

EXOSKELETON

An articulated mechanism whose joints correspond to those of a human arm and, when attached to the arm of a human operator, will move in correspondence to his. Exoskeletal devices are sometimes instrumented and used for master-slave control of manipulators.

JOYSTICK

A movable handle which a human operator may grasp and rotate to a limited extent in one or more degrees of freedom, and whose variable position or applied force is measured and results in commands to a control system.

REPLICA MASTER

A control device which duplicates a manipulator arm in shape. Control is achieved by servoing each joint of the manipulator to the corresponding joint of the replica master.

SWITCH CONTROL

Control of a machine by a person through movement of a switch to one of two or a small number of positions.

SYMBOLIC CONTROL

Pertaining to control by communication of discrete alphanumeric or pictorial symbols which are not physically isomorphic with the variables being controlled, usually by a human operator.

A device for effecting such control. Compare to analogic control.

TEACH

To program a manipulator arm by guiding it through a series of points or in a motion pattern which is recorded for subsequent automatic action by the manipulator.

TEACHING INTERFACE

The mechanisms or devices by which a human operator teaches a machine. (See teach.)

ROBOT PROGRAMMING LANGUAGE

A computer language especially designed for writing programs for controlling robots.

13. COMMUNICATIONS

ANALOG COMMUNICATIONS

Transmission of information in the form of a continuously varying physical quantity.

DIGITAL COMMUNICATIONS

Transmission of information in the form of discrete states.

SERIAL COMMUNICATIONS

Transmission of digital data on a single channel where data bits occur serially in time.

PARALLEL COMMUNICATIONS

Simultaneous transmission of digital data bits over separate channels.

COMMUNICATIONS LINK

A path over which information can be transmitted from one point to another. Typically for computer communications this takes the form of a wire or optical fiber.

MODULATOR-DEMODULATOR (MODEM)

An electronic device that sends and receives digital data using telecommunication lines. To transmit data, the digital signals are used to vary (modulate) an electronic signal that is coupled into the telecommunication lines. To receive data, the electronic signals are converted (demodulated) to digital data.

ACOUSTIC COUPLER

An electronic device that sends and receives digital data through a standard telephone handset. To transmit data, the digital signals are converted to audible tones that are acoustically coupled to a telephone handset. To receive data, the acoustically coupled audible signals are converted to digital signals.

BAUD

A unit of signalling speed equal to the number of discrete conditions of signal events per second.

FULL DUPLEX

In communications, pertaining to simultaneous two-way independent transmission in both directions.

HALF DUPLEX

In communications, pertaining to alternate, one-way-at-a-time, transmissions.

RS 232

A standard electrical interface for connecting peripheral devices to computers. Maximum range 40 feet and a maximum speed of 20,000 baud.

RS 449

A general purpose interface standard for data terminal equipment and data circuit-terminating equipment employing serial binary data interchange. Was developed to overcome some of the inherent limitations of RS-232. The standard defines the mechanical specifications for the connectors and the function of each circuit. Electrical standards suggested for use with RS-449 are RS-422 (balanced) with a maximum line length of 4000 feet and maximum frequency of 10 M baud, and RS-423 (unbalanced) with a maximum line length of 4000 ft. and a maximum frequency of 100K baud.

ASCII

American Standard Code for Information Interchange, a common coding scheme for alphanumeric characters and terminal control interfacing.

PROTOCOL

The procedural rules for controlling data communications between devices in computer systems.

ERROR CONTROL PROCEDURE

A method of detecting and recovering from errors occurring in transmitted data. Typically employs methods such as parity, Cyclic Redundancy checks and Frame Sequence Numbering to detect errors, plus a Request for Retransmission to recover.

ECHO CHECK

A method of checking the accuracy of transmission of data in which the received data are returned to the sending end for comparison with the original data.

HDLC (HIGH-LEVEL DATA LINK CONTROL)

A bit oriented protocol for managing the flow of information on a data communications link. Supports full or half duplex, point-to-point or multi-point communications using synchronous data transmission techniques. Employs a cyclic redundancy error check algorithm.

SDLC (SYNCHRONOUS DATA LINK CONTROL)

A bit oriented protocol for managing the flow of information on a data communications link. Supports full or half-duplex, point to point, multipoint, and loop communications using synchronous data transmission techniques. Employs a cyclic redundancy error check algorithm.

BI-SYNC (BINARY SYNCHRONOUS COMMUNICATIONS)

A character oriented protocol for managing the flow of information on a data communications link. Employs a defined set of control characters and control character sequences to synchronously transmit binary coded data between stations in a half-duplex manner. Implements a BCC (Block Check Character) error check algorithm.

ADCCP (ADVANCED DATA COMMUNICATIONS CONTROL PROCEDURE)

The proposed American National Standard for a bit oriented synchronous data communications protocol. Supports full or half duplex, point-to-point or multipoint communication. Employs a cyclic redundancy error check algorithm.

POLLING

A technique by which each of the terminals sharing a communications line is periodically sampled or interrogated to determine whether it requires servicing.

BUS

One or more conductors used for transmitting signals or power.

An information coding scheme by which different signals can be coded and identified when sharing a common data channel.

BYTE

A unit of computer stored information usually 8 bits in length.

14. ECONOMIC ANALYSIS

CYCLE TIME

The period of time from starting one machine operation to starting another (in a pattern of continuous repetition).

DUTY CYCLE

The fraction of time during which a device or system will be active, or at full power.

FLOOR-TO-FLOOR TIME

The total time elapsed for picking up a part, loading it into a machine, carrying out operations and unloading it (back to the floor, or bin or pallet, etc.). Generally applies to batch production.

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